CONTAINER NUTRIENT MANAGEMENT PRACTICES

Introduction

The goal of a fertilization program is to apply the minimal amount of nutrients that result in the desired growth rate, flower production, foliage color enhancement, or expected plant quality. Minimal amounts of fertilizer needed to achieve the desired response are impacted by container irrigation management practices that were previously discussed, and the substrate, which is discussed below. Considering these factors, nursery operators can develop a nutrient management plan and achieve minimal fertilizer losses from containers.

Container Substrates

Many terms including soil, media, soilless media, medium, potting or container mixes, and substrates are used to describe potting materials for growing plants. However, many of these terms are imprecise or can be confusing. Container mixes or potting mixes imply that more than one component is used in potting and growing plants. The term "substrate" avoids much of the confusion of other terms and is descriptive of the entire composition. Substrate is the term used in Europe and most other parts of the world to describe the components of the root ***rhizosphere*** within containers.

Many materials are used as nursery container substrates. The predominant components in the southeastern U.S. are pine bark, sand, and sphagnum peat moss.

Some alternative materials that have been used include pine tree residuals, composted hardwood bark, composted yard wastes and animal wastes, composted biosolids, composted cotton gin wastes, municipal compost, rice hulls, wood shavings, peanut hulls, and pecan shells. Substrates containing as much as 25-50% (by volume) compost are generally acceptable. The wetability, stability, chemical, and physical characteristics may limit the portion of alternative materials that can be used in a potting substrate. Unstabilized organic components or components that have not been aged may decompose rapidly, leaving a once full container three-fourth's full in a few weeks or months. Some composted materials lack the coarse large particles necessary for adequate aeration and limit their use as a container substrate. Composted animal wastes and mushroom compost characteristically have high salt levels, and therefore are limited to 10 to 20% of the substrate volume.

 # 81 **Container substrate components should be selected for plants and management needs.**

 # 82 **Substrate components should be stable and not decompose rapidly.**

 # 83 **Organic substrates should be free of weed seed, nematodes, pathogens, and chemical contaminants.**

 # 84 **Substrates should be stored on concrete slab where water never collects.**

 # 85 **Runoff from substrate storage area should be contained or directed through vegetative filters if substrate is amended with fertilizer.**

 # 86 **Areas surrounding substrate storage should be kept mowed to prevent weed seeds from blowing onto the substrate inventory. Sanitation is the first step toward a weed free nursery.**

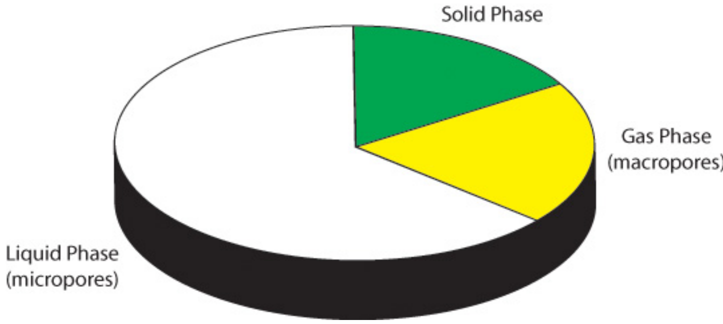
Container Substrate Physical Properties

A container substrate is composed of solid, gas, and liquid phases. For container substrates, these phases are usually described in terms of physical characteristics such as ***bulk density***, air space, and container moisture capacity. Because substrate physical characteristics dictate how much water and oxygen are available to roots, they have a major impact on plant growth. Therefore, a fundamental understanding of these physical characteristics is essential to proper irrigation and fertilization management. The solid phase of a substrate is described by the term "bulk density" which refers to the weight of substrate per unit volume of substrate particles (g/cc oven dry weight). Bulk density values for dry pine bark range from 0.19-0.24 g/cc (12.0 lbs/cubic ft - 15.0 lbs/cubic ft) depending on the particle size distribution of the pine bark. Particle size distribution refers to sizes of particles (dust-like to chunks) that compose a substrate. Because pine bark is porous, the volume of solids composes a relatively low portion compared to volume of the gas and liquid portions.

The particle size distribution, particle density, and nesting of substrate component particles greatly influence the gaseous and liquid characteristics of a substrate (to be discussed). Many sizes of pine bark are available ranging from fine to coarse; the size to be used is dependent on the type of crop and production practices. Experience is usually the best judge of which to use. The gas phase of a substrate is typically referred to as pore spaces. Pore spaces exist between substrate particles and within particles and are a critical portion of the substrate because these pores hold oxygen, which is essential for root growth. The term "***total porosity***" refers to the total volume of pore space in a substrate and is expressed as a percentage of the total substrate volume. Recommended total porosity values range from 50-85%. The term "***air space***" refers to the fraction of air-filled large pores (macropores) from which water drains following irrigation. Air space values are also expressed as a percentage of the total substrate volume and recommended values range from 10-30%.

Peat moss, usually stored in bales, is mixed with other components to formulate a container substrate.

Pine bark should be stored on a concrete slab and occasionally turned if stored for long durations.



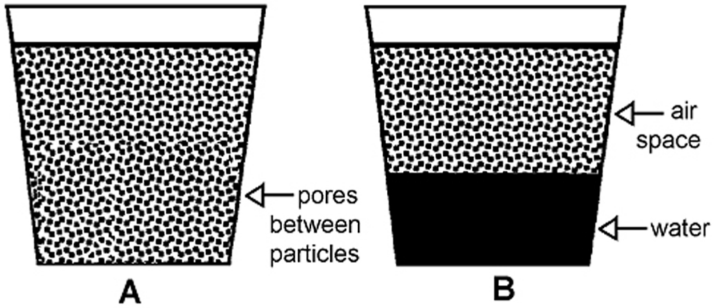
Depiction of solid, liquid, and gas phases of a pine bark substrate following irrigation and drainage (percent of total substrate volume).

The liquid phase of a substrate is termed the substrate solution and is often characterized by the term ***"container capacity."*** Container capacity is the maximum volume of water that a substrate can retain following irrigation and drainage (water holding capacity) due to gravity and is a measure of the water reservoir of a container. Following irrigation and drainage, an area of saturation, called a perched water table, exists at the bottom of a container. The height of the saturated area is greater for a fine textured (small pores) substrate than for a coarse textured (large pores) substrate. Above the ***perched water table*** there is a gradient of air-filled pore spaces; the amount of air-filled pores increase with the distance above the perched water table.

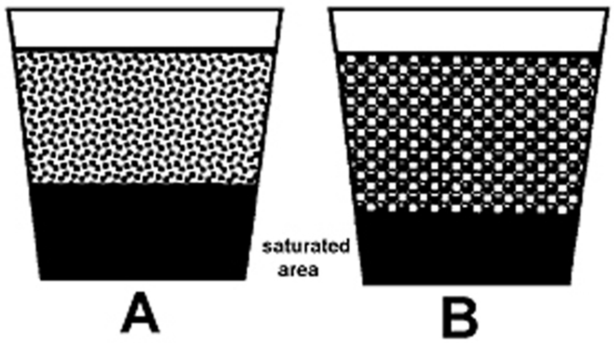
Container capacity is expressed on a volume basis as the percent of water retained relative to the substrate volume. Recommended container capacity values range from 45-65%. The water in a substrate can also be classified as "available" or "unavailable." Available water is that fraction of the water that can be absorbed by roots. Unavailable water (hygroscopic water) is that fraction of water that is held tightly to particles and is unavailable to roots.

Container dimensions can affect air space and container capacity. For example, a typical bark-filled 1-gallon container (six inches tall) might have a perched water table that is one inch tall. Thus, the perched water table occupies 1/6 (17%) of the container volume. Using the same bark, a flat (three inches tall) will also have a one-inch perched water table; however, the water table will occupy 1/3 (33%) of the flat volume. Bilderback and Fonteno, 1987, discuss further information on how container dimensions influences substrate characteristics.

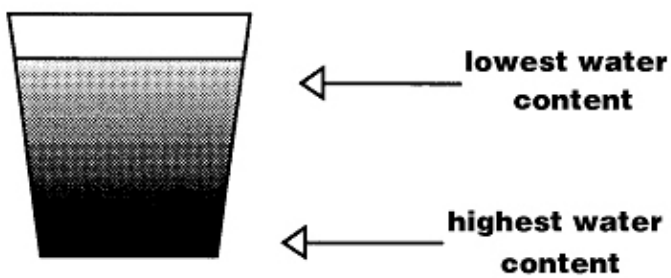
The physical properties of a substrate are also affected by amending the principle substrate with another ingredient. Amending pine bark with sand increases the amount of available water and bulk density; and decreases unavailable water, total porosity, and air space. Adding peat moss to pine bark also increases the amount of available water. The water in container must be balanced with air space to prevent root rot; and conversely, the substrate should retain water to minimize leaching. This delicate equilibrium can vary with plant species. Recommended physical characteristic values for nursery container substrates after irrigation and drainage are (percent volume): Total Porosity 50-85%; Air Space 10-30%; Container Capacity 45-65%; Available Water Content 25-35% and Unavailable Water Content 25-35%; and Bulk Density 0.19-0.70 g/cc. A substrate with a high proportion of coarse particles has a high air space and a relatively low water holding capacity. Consequently, leaching of pesticides and nutrients is likely to occur.



Air space refers to the air-filled pores before irrigation (A) and after irrigation and drainage (B). In general, a substrate with a relatively high proportion of micropores will have a high water holding capacity due to the attraction of water for the walls of small pores. Also, such a substrate will have a relatively low total porosity value because small particles tend to nest or settle within each other.



Container A is filled with small particles which fit together to form small pore spaces while the large particles used in container B form many larger pores.



Moisture gradient in container substrate at container capacity.

 # 87 **Physical characteristics of substrates should be tested and then used initially on a trial basis.**

 # 88 **Substrates should be used that have recommended physical characteristics.**

Air Space and Water Holding Capacity Measurements

A preferred method of measuring these physical properties is presented in the Australian Standards for Substrate Analysis (Standards Australian, 1989). Commercial laboratories can conduct tests to determine these physical properties ***(see Appendix B)***.

Handling Pine Bark Inventories

Loblolly and slash pine are the predominant species of pine grown and used for pine bark substrates in the southeastern U.S. Pine bark is generally considered to be non-phytotoxic and can be used without aging or composting but aging is preferred because fresh pine bark often has less than 20-30% fine particles. Fine particles less than 0.5 mm are generally considered responsible for moisture retention in containers. Aging six to eight months produces a more stable material and allows for the break down of larger particles, degradation of wood, ***cambium***, and complex compounds associated with the turpentine-like smell of fresh pine bark. Aged pine bark is sometimes referred to as composted bark. However, unless pine bark is amended with a nitrogen source, moistened, and turned periodically true composting does not occur.

Improper handling of pine bark inventories during storage can result in detrimental properties. Inventory windrows should be turned several times during aging and moistened if dry. If windrows of inventory are stacked greater than eight feet high or compacted by equipment, air exchange in windrows can be greatly reduced resulting in an accumulation of alcohols or ***acetic acid*** or both. Inventory windrows can reach temperatures of 180°F or higher. Steam rising from windrows indicates loss of moisture. Dry areas may contain less than 34% moisture content by weight and cannot be readily wetted. Plants potted from these areas may die due to inadequate moisture retention. Areas below these dry areas may be ***anaerobic***. Nursery personnel should check the electrical conductivity and pH of these areas using a 2:1 water to bark extraction. Electrical conductivity (soluble salts) of 2.5 mmhos/cm and pH values below 3.5 has been reported. These conditions can cause death especially for bare rooted transplants.

Pine bark in unturned inventories may also develop high fungal populations marked by clouds of spores when disturbed. If these inventories are used for potting, rapid growth of ***mycelium*** may make wetting of substrate in containers difficult and may result in crop losses. To avoid problems related to inventory storage of pine bark, nursery personnel should observe the condition of inventories at delivery and during storage. If inventories are excessively hot and steamy or clouds of spores are observed, moisten the new inventory, and check pH and electrical conductivity. If test results exceed identified parameters, turn or mix inventory and moisten if needed. Consider not using the inventory until test results are satisfactory.

 # 89 **Pine bark should be checked for moisture content, heat, spores, pH and electrical conductivity when turning inventory windrows.**

Front end loaders can be used to turn potting substrate inventories.

Container Substrate Chemical Characteristics

Cation Exchange Capacity (CEC) indicates how well a substrate holds positively charged ions (cations) such as ammonium, potassium, calcium, and magnesium against leaching. Typical CEC values (meq/100 ml) for several container substrate components are: aged pine bark, 10.6; sphagnum peat moss, 11.9; vermiculite, 4.9; and sand, 0.5. The role of CEC is minimal in soilless substrates as related to plant nutrient uptake and leaching. Unlike a field soil, nutrients applied as a single application of a soluble granular fertilizer leach rapidly from the container substrate. Additionally, organic substrates have very little anion exchange capacity and pH does not influence nutrient availability to the degree it does in a field soil. The container system requires frequent irrigations because of the limited water volume of the substrate, consequently, irrigation is a predominate factor in controlling container substrate nutrient levels. Soluble fertilizers injected frequently through the irrigation system or ***controlled-release fertilizers*** should be used to provide a continuous supply of nutrients at optimal levels, but in small enough quantities to minimize nutrient loss due to leaching. Specific nutrient levels and pH required for container substrates are discussed in section on Interpretation of Substrate Extract Measurements.

Pre-Plant Fertilizer Applications

The growth substrate may be amended with dolomitic limestone and micronutrients prior to planting as well as nitrogen, phosphorus, and potassium in the form of a controlled-release fertilizer. Other amendments may include iron, sulfur, gypsum, and magnesium.

Dolomitic Limestone

Dolomitic limestone supplies Ca and Mg and neutralizes the ***acidity*** of the growth substrate. The quantity of dolomitic limestone added to the substrate depends on irrigation water alkalinity and Ca and Mg content, initial pH of growth substrate, and the plant species grown. Hollies, loropetalums, and ericaceous plants (e.g. azaleas) grow best in acid substrates, pH 4.5-5.5 and may not require limestone additions. Nandina, junipers, boxwood and many other plants including flowering shrubs, require a substrate pH of 5.5-6.5. Several species of trees have grown well without the addition of dolomitic limestone in pine bark substrates as long as the substrate pH was acidic and micronutrients were added. Dolomitic limestone (75% passing through a 100-mesh sieve and containing a minimum of 6% Mg) amendments of 4-6 pounds per cubic yard are sufficient to meet the needs of most plants requiring limestone additions. Limestone amendments may be effective for up to two growing seasons depending on limestone particle sizes and hardness. A dolomitic limestone amendment is usually not needed if the irrigation water has an alkalinity or hardness above 100 ppm and contains Ca and Mg concentrations above 40 and 20 ppm, respectively.

 # 90 **When dolomitic limestone is needed, 4-6 pounds per cubic yard should be used for most plants.**

Micronutrients

Micronutrients are essential for plant growth, but only a small quantity is required. There are several micronutrient fertilizers sold commercially. These fertilizers usually contain the essential micronutrients and are added to the container substrate as an amendment. Micronutrient amendments can be effective for up to two growing seasons unless irrigation water alkalinity is high, in which case additional applications of micronutrients may be needed. Micronutrients are available as components in controlled-release fertilizers. Preliminary studies with container-grown shrubs (hollies, azaleas) and tree seedlings (pin oak, Japanese maple) indicate that controlled release fertilizers with micronutrients are effective in supplying micronutrients without the addition of micronutrient amendments. If composted yard debris, composted hardwood bark, or composted biosolids are 10% or greater by volume of the substrate, then micronutrient needs may be met by these components.

 # 91 **Micronutrient amendments should be applied according to manufacturer's recommendations listed on the product label.**

Iron sulfate is commonly added to pine bark substrates in areas where water alkalinity is high to provide sufficient iron to prevent chlorosis and to help slow the process of substrate pH increasing. Iron sulfate additions of up to 1.5 pounds per cubic yard in pine bark substrates can be used to reduce substrate pH for two to three months. Iron chelates are rarely used as amendments.

Macronutrients

Phosphorus leaches rapidly from soilless container substrates. Complete controlled-release fertilizers applied during the growing season should supply adequate phosphorus.

 # 92 **Superphosphate should not be added to the container substrate.**

Granular sulfur can be used to maintain an acidic pH in container substrates when problems occur with increasing pH during the production cycle. Granular sulfur will react slower than fine sulfur with a response being evident in three months. Begin by testing a granular sulfur product at the rate of 0.25 pounds per cubic yard and monitor substrate pH.

Gypsum (calcium sulfate) is used to provide calcium and sulfate-sulfur without increasing the pH of the substrate. Rates of 0.5-2.0 pounds of gypsum per cubic yard of substrate have been used effectively.

Magnesium deficiency can be a problem due to 1) the greater solubility of magnesium carbonate in dolomitic limestone compared to calcium carbonate, or 2) areas where there is an imbalance of calcium to magnesium in irrigation water. Magnesium sulfate can be used as an amendment to provide magnesium and sulfate-sulfur. However, magnesium sulfate is readily soluble and soon leaches from the container. Kieserite is another soluble form of magnesium that has a release period about twice that of magnesium sulfate. Several combination products of magnesium oxide and magnesium sulfate are available that provide a longer period of release. Magnesium oxide should be used with caution because the release rate is correlated with particle size (larger the particle, slower release) and it has the greatest potential to increase substrate pH (2.5 times greater than dolomitic limestone). Amendments of controlled-release magnesium products can be used. Controlled-release fertilizers with 1% magnesium have reduced or eliminated symptoms of magnesium deficiency.

 # 93 **Fertilizer should be mixed with substrate or subsurface applied at planting according to manufacturer's recommendation.**

 # 94 **Care should be taken to ensure the coating or covering on the fertilizer granules is not cracked or broken in the process of mixing fertilizer with the substrate.**

 # 95 **Substrates amended with fertilizers should be placed in containers within a few days to prevent salt buildup caused by high bulk substrate temperatures.**

Post-Plant Fertilizer Applications

One or more applications of a controlled-release fertilizer applied to substrate surface or a solution fertilizer applied through the irrigation system are often used to accomplish fertilization during production.

 # 96 **Fertilizer should be applied based upon plant need. This may vary with plant species and time of year. A fertilizer nutrient ratio of approximately 3:1:2, $N:P_20_5:K_20$ is preferred.**

Controlled-Release Fertilizer (CRF)

Controlled-release fertilizers supply essential plant nutrients for an extended period of time (months). Fertilizers are available that contain different mechanisms of nutrient release and contain different nutrients. Care must be taken to select the correct fertilizer for your specific purpose and geographic location. Because nutrient release from most products is primarily controlled by temperature, product selection would be different in warmer southern states compared to more northern Mid-Atlantic States.

Controlled-release fertilizer application rates will vary with product but will also depend on species and container size. The goal of a fertilization program is to apply the least amount of fertilizer for the desired growth so that nutrient leaching is minimal. Excessive irrigation may reduce the effectiveness of CRF fertilizers due to leaching of nutrients from container.

 # 97 **Controlled-release fertilizers should be uniformly mixed into the substrate prior to potting. This practice may be more economical than surface application after planting.**

 # 98 **Controlled-release fertilizers should be applied at manufacturer's recommended rates. Reapplication of a fertilizer occurs when substrate solution nutrient status is below desirable levels (see section on Monitor Container Substrate Nutrient Status).**

 # 99 **Application rates used in fall and winter (after first frost), should be one half the rates used in summer for the same type of production.**

 # 100 **Fertilizer should not be broadcast on spaced containers.**

Fertilizer in Irrigation Water

Another method is to apply a fertilizer solution through the irrigation system with the frequency of application and/or fertilizer concentration in the irrigation water dependent on nutrient concentration in the container substrate solution. CAUTION: when fertilizer is injected in the overhead irrigation system you will need to take steps to address the nutrient loading of the water leaving your property, because much of the water from overhead irrigation systems falls between containers. Fertilizing through the irrigation water is less of a concern for microirrigation systems in which irrigation water is delivered into the container. Even then, care should be taken to minimize leaching from the container to prevent nutrient laden runoff from entering surface or groundwater.

 # 101 **Runoff should be collected or steps taken to reduce nutrient levels in runoff water before water leaves the property if fertilizer was in overhead irrigation water. Collecting and recycling of runoff water is an appropriate and effective solution.**

Supplemental Fertilization

 # 102 **Supplemental fertilizer should be applied based on regular monitoring of EC levels in container substrate (see below) so desired nutritional levels are maintained.**

 # 103 **Individual elements or a combination of elements should be injected in concentrations slightly less than desirable levels maintained in the growth substrate (Table 6).**

 # 104 **Surface-applied fertilizer should be applied to small blocks or groups of plants, thus minimizing nutrient loss and nutrient loading of runoff water.**

Apply controlled-release fertilizer uniformly with a spoon, drop-tube, or metering devise.

 # 105 **Plants should be grouped according to their fertilizer needs so supplemental fertilizer applications are made only to plants requiring additional fertilizer (Table 7). This is particularly important when fertilizer is injected in irrigation water.**

 # 106 **Broadcast fertilizer applications should be avoided unless containers are placed beside each other.**

Record of Fertilizer Application

 # 107 **Keep accurate fertilization application records (as outlined in Table 5). This should include application rate (including supplemental applications) for each plant type and container size in addition to other important information (Table 5). This information may prove very valuable to document that you have followed recommended fertilizer management practices and as a valuable source of information in case plant abnormalities develop that may be attributed to fertilizer application.**

Monitor Container Substrate Nutrient Status

Environmental conditions influence the longevity of fertilizer release. Thus, to ensure adequate nutrient levels in the growth substrate, nursery operators should monitor container substrate nutrient status and use results to determine fertilizer reapplication frequency and rate, ensuring that desired levels are maintained. Periodic monitoring is important because excessive or inadequate nutritional levels may not be expressed by visual symptoms, although growth is reduced. High concentrations of nutrients can result from substrate components, inadequate irrigation frequency and duration, water source, and/or fertilizer materials and application methods. Container substrate nutritional levels may also rise during the over wintering of plants in polyhouses. Excessive nutrient concentrations injure roots, ultimately restricting water and nutrient uptake. Conversely, rainfall and excessive irrigation can leach nutrients from the container substrate resulting in inadequate nutritional levels and threaten water quality.

How Often to Monitor

Substrates used for long-term crops should be tested at least monthly, but biweekly monitoring during the summer may be necessary to track fluctuations in electrical conductivity (EC) which is used as a relative indicator of the nutritional status of the container substrate. Even when controlled-release fertilizers are used, substrate nutritional levels will gradually fall during the growing season to levels that may not support optimal growth. Care must be taken to monitor substrate EC to ensure that adequate nutrients are available for plant growth but also to ensure that containers do not have excessive levels of nutrients. It is advisable to monitor EC (salt levels) in containers about one week after planting to ensure that high levels of salts are not present due to fertilizer. Excessive fertilizer salt levels can also develop in substrates due to high temperature during decomposition.

Fertilizers are surface-applied to small group of plants.

Table 5. Fertilizer application record sheet.

Date	*Field Location*	*Fertilizer/ Longevity Analysis*	*Brand Name*	*Amount Applied**

*Application Frequency**	*Plant Name*	*Container Size*	*Env't'l. Condition*	*Area (acres)*

**Recorded as grams per container (surface or subsurface application) or pounds per cu. Yd. or ppm N in the irrigation water. Frequency of application is very important for fertilizer applied with irrigation water.*

Table 6. Maintain these desirable nutritional levels in the container substrate for plants with medium to high nutritional requirements. Levels are for interpretation of the Pour-through (PT) and Suction Lysimeter (SL) when fertilizing with solution or liquid fertilizer alone or in combination with controlled-release fertilizers (CRF) or using only controlled-release fertilizer.

Analysis	***Desirable levels***	
	Solution only or CRF and solution	***CRF fertilizer only***
pH	4.5 to 6.5	4.5 to 6.5
Electrical conductivity, mmhos/cm (dS/m)	0.8 to 1.5	0.5 to 1.0
Nitrate-N, $N0_3$-N mg/L (ppm)	50 to 100	15 to 25
Phosphorus, P mg/L	10 to 15	5 to 10
Potassium, K mg/L	30 to 50	10 to 20
Calcium, Ca mg/L	20 to 40	20 to 40
Magnesium, Mg mg/L	15 to 20	15 to 20
Manganese, Mn mg/L	0.3	0.3
Iron, Fe mg/L	0.5	0.5
Zinc, Zn mg/L	0.2	0.2
Copper, Cu mg/L	0.02	0.02
Boron, B mg/L	0.05	0.05

Levels should not drop below these during periods of active growth. Plants with low nutritional requirements may grow adequately with lower nutrient levels. See **Table 7** for plants with a low nutritional requirement.

 # 108 **During the growing season, container substrates should be monitored every two to four weeks.**

High temperatures in overwintering structures can result in nutrient release from controlled-release fertilizers. Monitor substrate electrical conductivity two or three times during the winter to ensure levels are not toxic.

 # 109 **Substrate electrical conductivity should be monitored two or three times during the winter months.**

Substrate Monitoring Considerations

Nutrients may accumulate in specific locations in substrate due to irrigation patterns and fertilization methods. Therefore, one isolated sample will not give an accurate representation of the nutrient status of the substrate. Collect several (3-4) representative substrate samples to ensure that samples represent the growth substrate being considered.

Substrate Sampling Methods for Nutrient Extraction

Several procedures have been used to extract the nutrient solution from the container substrate for nutritional analyses. The ***Pour-through*** (PT) or ***leachate*** collection method enables rapid sample collection from containers that are easy to lift. For larger or heavier containers (for example #15 or #25) a modification of the Pour-through using ***suction lysimeters*** (SL) is recommended. The PT and SL are simple, nondestructive procedures that are easy for nursery operators to perform. PT and SL methods are described in detail in **Appendix C**. These methods of nutrient solution extraction allow nursery operators to make quick determinations of substrate electrical conductivity and pH. For additional analyses, samples can be sent to a laboratory ***(see Appendix A)*** for determination of elemental concentrations. All laboratories do not use the same procedures so test results can differ between laboratories. Consequently, interpretation of results is very important.

Container substrate solution extraction for small containers is accomplished with the Pour-through.

A Suction Lysimeter remains in the large container for repetitive sampling of the container solution.

The Pour-through (PT) and Suction Lysimeter (SL) for Monitoring Nutrients in Container Substrates

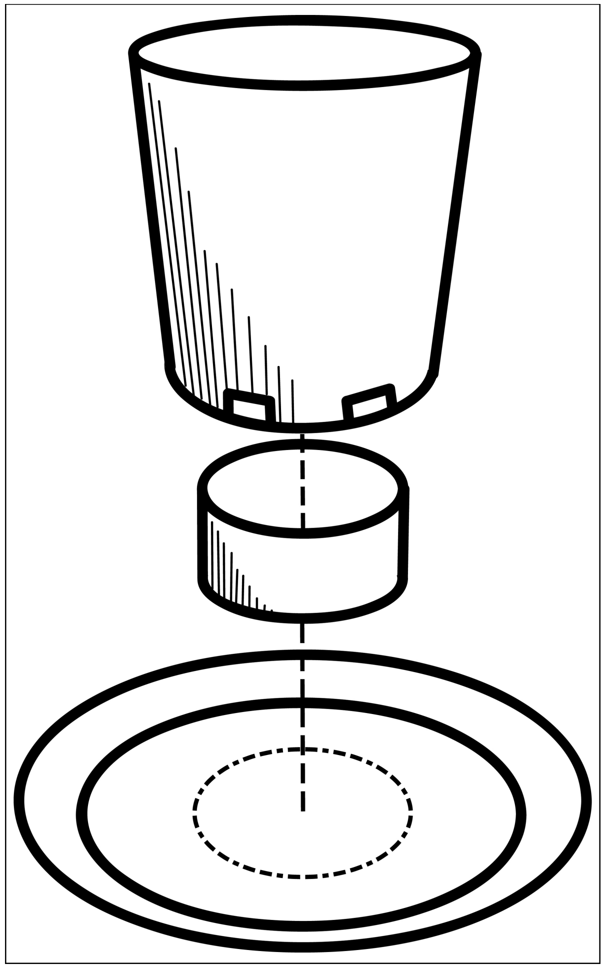
General Considerations

Container plants should be irrigated using your normal practices one to two hours before monitoring nutrients. For accurate and comparable monitoring events, containers should be at or near container capacity (excess water has drained from container). Monitoring should be performed on containers (usually 3-5) that are representative of a particular species, or irrigation or fertilization regimes.

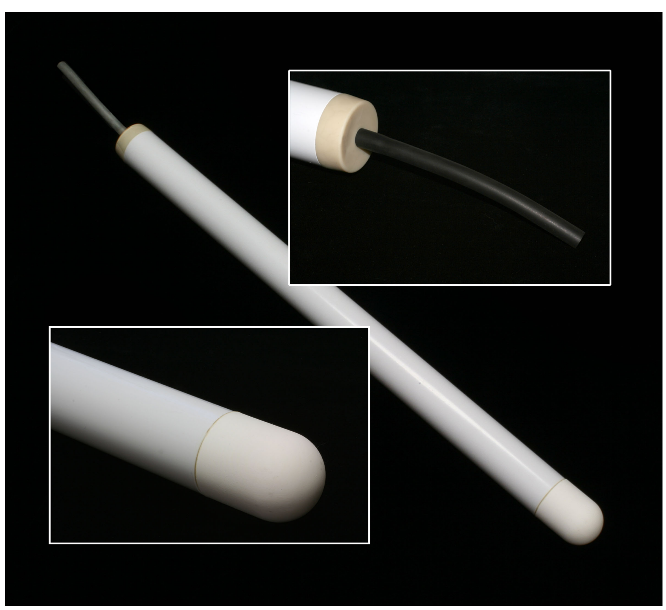
Small Containers

After irrigation and excess water drains from container, place each test plant over a collection reservoir that will catch drainage from all holes. The bottom of the container should be elevated above the collection reservoir so bottom of container does not contact leachate or extract that drains. Apply sufficient distilled water (tap water is fine if of reasonable quality) in a circular motion to the surface of container substrate so that about 50 ml (1.5 oz) of leachate or extract is collected. **Table 8** provides approximate volumes to apply to containers of different sizes.

Collect all the leachate from each container. The amount collected will vary but should not affect pH or EC readings. Usually collecting 50 ml is sufficient. Applying an excessive volume of water to a container can result in low EC readings. It is important to keep leachate from contacting bottom of container because salts that precipitated and accumulated on or around the holes of container could influence solution salinity, resulting in erroneous EC readings.



The container must be elevated to avoid contamination of the leachate.



Lysimeter composed of hollow tube (2 ft x 2 in) with porous ceramic cup at bottom.

Large Containers

It is very difficult to lift large containers and find sufficiently large collection reservoirs so suction lysimeters can be used to extract the substrate solution from these containers. The lysimeter consists of a porous ceramic cup attached to the bottom of tube. Lysimeters can be purchased from SoilMoisture Equipment Corp., P.O. Box 30025, Santa Barbara, CA 03105: http://www.soilmoisture.com. Model 1900 L24 with a one-half-bar air-entry value, vacuum pump 2005G2, and 1000K2 extraction kit are recommended. Other vacuum pumps and extraction methods are also acceptable.

It is recommended that lysimeters be installed for duration of production. Make a pilot hole, approximately one half the diameter of the lysimeter and vertically through the substrate to the bottom of the container. A two-foot-long length of a one inch metal bar is adequate for this purpose. The difference in diameter between the pilot hole and the lysimeter ensures a tight fit between the substrate and the lysimeter.

One to two hours following irrigation, a vacuum pump is used to extract water from the container through the ceramic cup and into the lysimeter. The vacuum should not exceed 50 cbar. Immediately seal the lysimeter port to maintain the vacuum. After 5-15 minutes, about 50 ml of solution or extract will be in bottom of the lysimeter. Open the top of lysimeter (you may hear the release of the remaining vacuum) and draw out the solution with a syringe.

The solution collected can be analyzed for EC, pH, or complete nutrient analysis. Three or four lysimeters should be installed within a block of plants of the same species, irrigation regime, or fertilization regime.

Interpretation of Substrate Extract Measurements

Interpreting the EC and pH readings may require some practice and a season-to-season knowledge of the crops in question. These measurements are often sensitive to changes in cultural conditions, including changes in fertilization and watering practices, and to changes in temperature, precipitation, and water quality. For these reasons, it is important to maintain consistency in the extraction method and the conditions in which used. However, repeated measurement of EC and pH over time has allowed us to make some general recommendations based on potential availabilities or toxicities of nutrients at different pH values, and on relationships between EC and nutrients in extract solution.

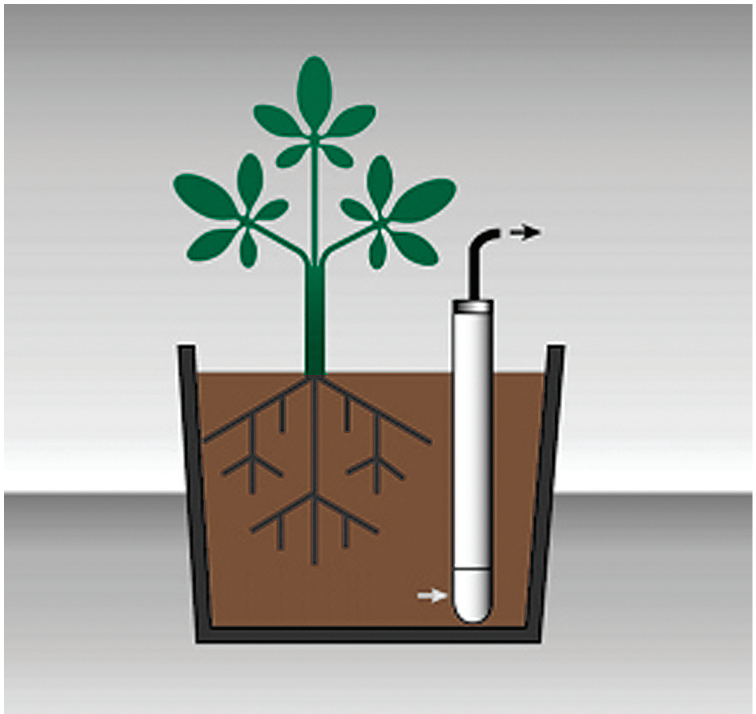
It is important to calibrate the pH and EC meters just prior to use. Use manufacturers' recommended standards and make sure they are not outdated. Follow manufacturers' instructions for calibrations and other determinations.

The pH and EC determinations for each substrate liquid extract should be completed within one to two hours after sampling. Record your results along with cultural information about plants tested. Cultural information, such as irrigation and fertilization regimes, can be very helpful for making management decisions in the future.

Electrical Conductivity

Most fertilizers (except urea) are salts and when fertilizers are in solution they conduct electricity. Thus, the electrical conductivity of a substrate solution is indicative of the fertilizer level that is available to plant roots. Container substrate nutritional levels in **Table 6** may be compared to those obtained from plants sampled with the PT or SL methods of extraction. If nutritional levels that result from application of controlled-release fertilizers should drop below desirable levels during periods of active plant growth, then reapplication should be considered to maintain optimal levels in the substrate. Application of fertilizer through the irrigation system may also be adjusted to compensate for either too high or too low EC readings.

Low EC values may indicate over-irrigation and excessive leaching of nutrients, periods of minimal release of controlled-release fertilizer, or improper calibration of a fertilizer injector. Values considerably higher than those suggested; may indicate a poorly calibrated injector, over-application of granular or controlled-release fertilizer, improper release of controlled-release fertilizer, or under-irrigation and excessive accumulation of salts. Research-based knowledge of the appropriate nutrient levels for optimal plant growth is limited and there is no substitute for experience.



Lysimeter positioned in container.

 # 110 **Container substrate electrical conductivity levels should be maintained between 0.8-1.5 mmhos/cm for plants fertilized with solution fertilizer only or with the combined use of controlled-release and solution fertilizer. Container substrate electrical conductivity levels should be maintained between 0.5-1.0 mmhos/cm for plants fertilized with controlled-release fertilizer only. These ranges (see Table 6) are applicable to most container-grown landscape plants.**

Plants with a low nutrient requirement (**Table 7**) may grow adequately with nutrient levels lower than those given in **Table 6**. Many herbaceous annual and perennial plants have higher nutritional requirements. Recent research suggests that EC measurements of 1.0-2.5 mmhos/cm may correspond to adequate nutrition for these plants. Particular adjustments must be made for plants known to be sensitive to fertilizer additions.

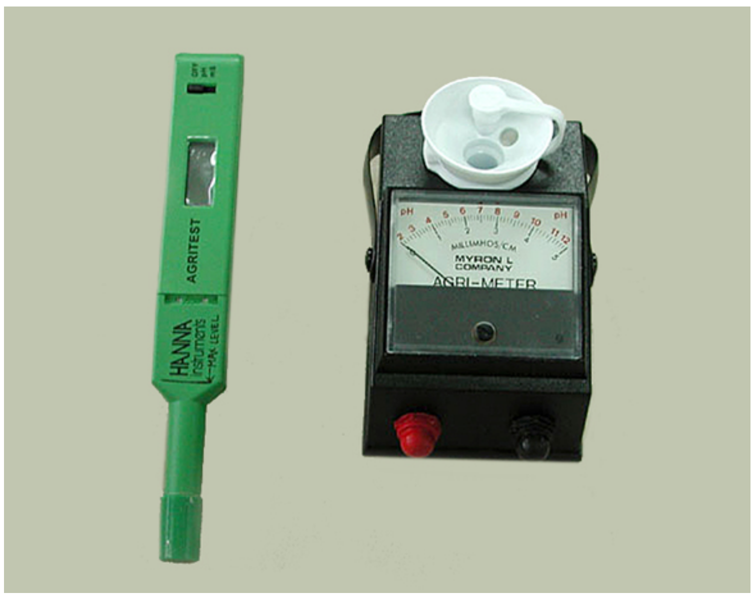
 # 111 **Irrigation water electrical conductivity should be determined. The irrigation water electrical conductivity enables you to know the contribution of your water to the solution extract electrical conductivity and this should be considered when interpreting the substrate electrical conductivity.**

pH

Substrate solution pH may impact nutrient availability. The recommended solution pH varies with different crops, but a range between 4.5 and 6.5 is considered adequate for most crops grown in pine bark-based substrate. Fertilizer formulations may affect substrate solution pH. Gradual increases or decreases in pH throughout production should be noted and referred to a plant nutrition specialist if pH exceeds the recommended range for your crops.

Excessively high or low irrigation water pH values may indicate problems with water quality and the need to use substrate amendments to align substrate solutions with recommended nutrient ranges for optimal plant growth. A reputable water-testing lab can conduct a complete irrigation water analysis.

 # 112 **pH of substrate and irrigation water should be determined as per container substrate monitoring schedule.**



The substrate extract solution is tested for soluble salts using an electrical conductivity (EC) meter.

Table 7. A partial list of container-grown plants with their nutritional requirements is given below. Plant Requirements will vary depending on growth rate desired and cultural conditions.

Scientific name	***Common name***	***Nutrient Requirement***
Abelia x grandiflora	Glossy Abelia	medium
Acca sellowiana	Pineapple Guava	medium
Acer palmatum	Japanese Maple	medium
Acer rubrum	Red Maple	medium
Aspidistra elatior	Cast Iron Plant	medium
Aucuba japonica	Aucuba	medium
Berberis thunbergii	Japanese Barberry	medium
Betula nigra	Betula	high
Buddleja davidii	Butterfly-bush	high
Butia capitata	Pindo Palm	medium
Buxus microphylla	Japanese Boxwood	medium
Buxus spp. 'Wintergreen'	Boxwood	high
Callicarpa japonica	Japanese Beautyberry	high
Callistemon spp.	Bottlebrush	high
Calycanthus floridus	Sweetshrub,Carolina Allspice	medium
Camellia japonica	Camellia	low
Camellia sasanqua	Sasanqua Camellia	low
Carpinus caroliniana	American Hornbeam	medium
Cedrus deodora	Deodar Cedar	medium
Cercis canadensis	Redbud	medium
Chamaecyparis pisifera	Falsecypress	medium
Chamaerops humilis	European Fan Palm	medium
Chionanthus virginicus	Gray-beard	medium
Clethra alnifolia	Clethra	medium
Cornus florida	Dogwood	medium
Cornus kousa	Kousa Dogwood	medium
Cortaderia selloana	Pampas Grass	low
Cryptomeria japonica	Japanese Cedar	medium-high
Cuphea hyssopifolia	False Heather	high
x Cupressocyparis leylandii	Leyland Cypress	high
Cupressus arizonica	Arizona Cypress	medium
Cycas revoluta	Sago Palm	medium
Daphne odora	Winter Daphne	low
Dietes vegeta	African Iris	medium
Echinacea pallida	Pale Coneflower	medium
Eriobotrya japonica	Loquat	low
Euonymus spp.	Euonymus	high

Table 7. *(continued)*

Scientific name	***Common name***	***Nutrient Requirement***
Eupatorium purpureum atropurpureum	Joe Pye	low-medium-high
Fatsia japonica	Fatsia	medium
Galphimia glauca	Thryallis	medium
Gardenia jasminoides	Gardenia	medium
Gelsemium sempervirens	Carolina Jasmine	high
Ginkgo biloba	Ginkgo	medium
Hedera helix	English Ivy	medium
Hemerocallis spp.	Daylily	medium
Hibiscus rosa-sinensis	Hibiscus	high
Hibiscus syriacus	Shrub Althaea	high
Hydrangea macrophylla	Hydrangea	low
Hydrangea quercifolia	Oakleaf Hydrangea	medium
Ilex cornuta '*Burfordii Compacta*'	Dwarf Burford Holly	high
Ilex crenata	Japanese Holly	high
Ilex glabra	Inkberry Holly	medium
Ilex vomitoria '*Nana*'	Dwarf Yaupon Holly	high
Ilex x attenuata '*Fosterii*'	Foster's Holly	high
Ilex x attenuata '*East Palatka*'	East Palatka Holly	medium
Ilex x attenuata '*Nellie R. Stevens*'	Nellie R. Stevens Holly	high
Ilex x meserveae spp.	Blue Hollies	medium
Illicium parviflorum	Anise	medium
Itea virginica	Sweetspire	medium
Ixora coccinea	Ixora	medium
Juniperus chinensis '*Blue Vase*'	Blue Vase Juniper	medium
Juniperus chinensis '*Sargentii*'	Sargent's Juniper	medium
Juniperus chinensis '*Torulosa*'	Torulosa	medium
Juniperus conferta '*Blue Pacific*'	Blue Pacific Juniper	medium
Juniperus davurica '*Parsonii*'	Parson's Juniper	medium
Juniperus procumbens	Japgarden Juniper	medium
Kalmia latifolia	Kalmia	low
Lagerstroemia indica	Crape Myrtle	medium
Lantana montevidensis	Trailing Lantana	low
Leucophyllum frutescens	Texas Sage	low
Ligustrum japonicum	Waxleaf Ligustrum	high
Liriope muscari	Lilyturf	medium
Liriope spp. '*Evergreen Giant*'	Evergreen Giant Liriope	low
Lonicera spp.	Honeysuckle	high
Loropetalum chinense	Fringe Bush	medium

Table 7. *(continued)*

Scientific name	***Common name***	***Nutrient Requirement***
Magnolia grandiflora	Southern Magnolia	medium
Mahonia bealei	Leatherleaf Mahonia	medium
Mahonia fortunei	Fortune's Mahonia	medium
Myrica cerifera	Waxmyrtle	low
Nandina domestica	Heavenly Bamboo	medium
Nerium oleander	Oleander	low
Osmanthus fragrans	Sweet Olive	medium
Pennisetum setaceum	Red Fountain Grass	low
Photinia x fraseri	Fraser's Photinia	medium
Pinus spp.	Pine	low
Pittosporum tobira	Pittosporum	medium
Platycladus x '*Green Giant*'	Green Giant Arborvitae	medium
Plumbago auriculata	Plumbago	low
Podocarpus macrophyllus	Podocarpus	medium
Prunus caroliniana	Cherrylaurel	low
Prunus laurocerasus '*Schipkaensis*'	Cherrylaurel	medium
Quercus laurifolia	Laurel Oak	medium
Quercus nuttallii	Nuttal Oak	high
Quercus phellos	Willow Oak	high
Quercus virginiana	Live Oak	medium
Rhododendron austrinum	Florida Flame Azalea	low
Rhododendron canescens	Pinxter Azalea	low
Rhododendron spp.	Azalea, Rhododendron	low
Spiraea japonica '*Little Princess*'	Little Princess Spiraea	medium
Spiraea spp.	Spiraea	high
Spiraea x bumalda '*Anthony Waterer*'	Anthony Waterer Spiraea	medium
Taxodium distichum	Bald Cypress	low
Ternstroemia gymnanthera	Cleyera	medium
Trachelospermum asiaticum	Dwarf Jasmine	medium
Trachycarpus fortunei	Windmill Palm	medium
Tsuga canadensis	Canadian Hemlock	low-medium
Ulmus parvifolia	Chinese Elm	medium
Viburnum awabuki '*Chindo*'	Chindo Viburnum	high
Viburnum spp. '*Shasta*'	Shasta Viburnum	medium
Viburnum suspensum	Sandankwa Viburnum	medium
Washingtonia robusta	Washington Palm	medium
Zamia floridana	Coontie	medium

Table 8. Approximate volume of water to apply to obtain 50 ml (2.0 oz) of leachate.

Container size	Water to apply	
	Milliliters	Ounces
4 to 6 inch	75	2.5
6.5 inch azalea	100	3.5
1 quart	75	2.5
1 gallon	150	5
3 gallons	350	12
5 gallons	550	18.5
Trays (amount/cell)	50	2

Containers should be at container capacity for about 30 minutes (for cavities or cells in flats and small containers) to two hours (for larger containers) before applying water. The volumes of water are estimates; so actual amount may vary depending on crop, substrate, or environmental conditions. Adapted from 1, 2, 3's of Pour-Thru, North Carolina State University, Whipker et al. 2001.

Fertilizer Storage Considerations

Granular and Solution

Local, state, and federal regulations regarding codes for storage structure compliance may apply to your situation.

113 **Solution fertilizer tanks should have secondary containment areas for tank contents in case of overflow or leaks.**

Foliar Analyses

Foliar analyses may be used to verify or diagnose deficiencies or toxicities during the growing season or to determine elemental status of plant tissue in fall or winter prior to spring flush of growth. A well-designed fertility program can eliminate the need for tissue testing.

Tissue Sampling Considerations

Generally, plants grown under similar conditions can be treated as a group when sampling, although samples from different species or cultivars should not be mixed. A tissue sample must be representative of plants sampled. An acre of plants of the same species that had been treated similarly would require only one to three composite samples while plants of the same species that have been grown under different cultural or environmental conditions, should be sampled separately.

114 **Tissue samples should be representative of plants being sampled.**